HEP as a Planning Tool: An Application to Waterfowl Enhancement

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HEP as a Planning Tool: An Application to Waterfowl Enhancement

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Introduction

To many, the principal role of wildlife agencies in public and private resource development has been that of impact mitigation. With known or pending habitat damage, biologists have to develop mitigation or compensation plans. Unfortunately, once in a mitigation framework, they are in a no-win situation, seeking remedial action at best. Yet, the potential exists for cooperative project planning, thereby facilitating mitigation of impacts *before* they occur, and enhancement of environmental amenities through project development. In fact, such planning is mandated by federal legislation (e.g., National Environmental Policy Act, Fish and Wildlife Coordination Act, Outdoor Recreation Act, etc.).

In the spirit of these legal mandates, the biological profession must recognize and fulfill its role in planning; rarely have biologists been effective in incorporating fish and wildlife habitat improvement into project designs. Presently, environmental quality and enhancement often are regarded as obstacles to development, partly because quantitative information that can be easily integrated into the planning process is lacking. However, through proper biological planning, these tradeoffs can be recognized and complementary benefits incorporated into project design. Moreover, such an integrated planning process would be an immense aid to more efficient management of state, federal and even private fish and wildlife resources.

Two factors dominate the planning process: (1) biological or habitat models linked to specified management activities, and (2) economic choice criteria to evaluate tradeoffs and/or complementary benefits between biological and other project purposes. Biological models can provide measures of change in environmental conditions and the response of a wildlife species to these habitat changes. Inability to quantify this potential response has been a significant deterrent to cooperative planning. However, an additional modeling framework is necessary to link the biological model and attendant management activities to an economic choice criterion. It is this linkage that will aid decision makers in the evaluation of alternative project plans, and is the focus of this paper.

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The Habitat Evaluation Procedures (HEP) can serve as the requisite biological model (U.S. Fish and Wildlife Service 1981). The remainder of this paper demonstrates how HEP can be linked to an optimization framework that explicitly models the continuum of biological responses to various management or enhancement practices available to wildlife managers. Cost effectiveness or cost per unit of habitat or wildlife produced can be estimated. Decision makers can then select the management programs that provide the greatest increase in habitat/wildlife for a given dollar expenditure. This general framework is applied to mallard (*Anas platyrhynchos,* Linneaus) habitat management in a proposed 400,000-acre (162,000 ha) Bureau of Reclamation irrigation project in Washington's Columbia Basin.

Analytical Overview

HEP as a Biological Model

HEP was developed by the U.S. Fish and Wildlife Service for use in impact assessment and planning (see Schamberger and Farmer 1978, for the historical development of HEP).[1] While the HEP modeling process is discussed in considerable detail elsewhere (U.S. Fish and Wildlife Service 1981), a brief overview is provided here. This overview is intended to draw attention first to the level of detail required for a credible habitat model, and secondly, to illustrate the linkage between habitat models and management practices designed to alter habitat.

The HEP modeling process quantifies overall habitat suitability as a dimensionless value ranging from zero to one, the Habitat Suitability Index (HSI). HSI represents the capacity of a given habitat to support or produce a target species. The logic of an HSI model is illustrated in Figure 1, "A Breeding Habitat Suitability Index Model for the Common Mallard (*Anas platyrhychos,* Linneaus)."

Levels I through IV trace the relationship between overall habitat suitability and the measurable environmental variables needed to characterize the habitat potential of a given environmental setting. Overall habitat suitability for mallard breeding habitat (Level I) depends on the suitability of life requisite needs (Level II), i.e., nesting habitat, submersed food, and brood-rearing habitat. Each life requisite may be supplied by several different cover types (Level III). Since each cover type is different, a separate set of measurable environmental variables (Level IV) is required to define the adequacy of each cover type. Although the same environmental variable may be related to different cover types, e.g., vegetation density, separate measurement of the variable for each cover type satisfying a particular life requisite need is required to define the overall suitability of each cover type. For a detailed description of this specific mallard habitat model and supporting literature, see Hanson and Matulich (1982).

Aggregation and spatial interspersion of the measurable environmental variables into an HSI embodies the complexity of the environment being modeled. The more complex the environment, the greater the number of elements needed to define the system and the more intricate the linkages between the elements. By definition,

[1]Both the intent and application of HEP in planning appears to have been in developing mitigation strategies for known or anticipated habitat damage.

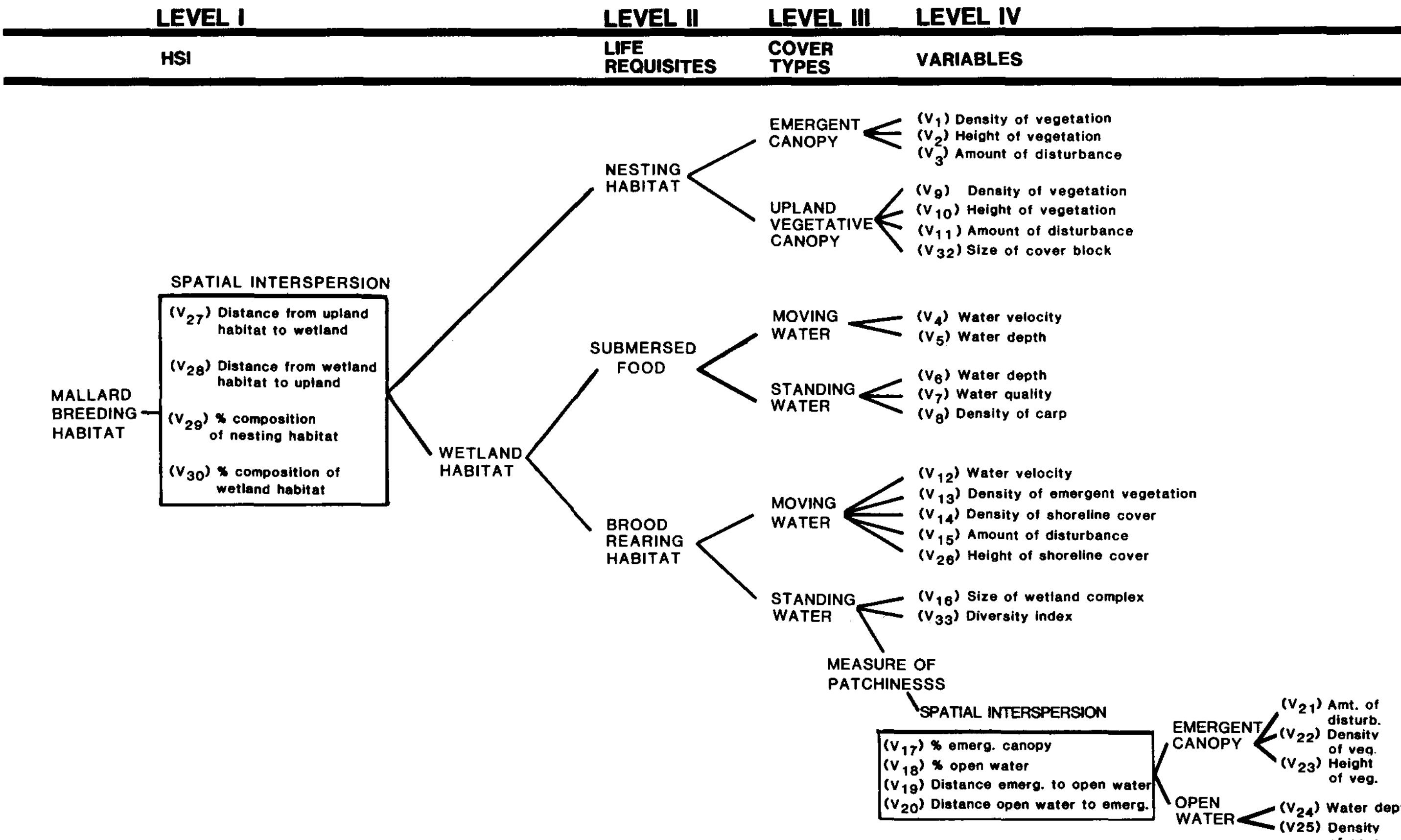

Figure 1. A breeding habitat suitability index model for the common mallard (*Anas platyrhynchos*, Linneaus).

all models are simplifications of reality. But to be useful in a predictive or planning sense, all dominant environmental factors and interactions should be incorporated. Figure 1 demonstrates the implication of modeling complex environmental systems. The complexity of this process is further demonstrated later in this paper when the mathematical representation of one part of this model is presented.

The HSI model depicts elementary habitat production relationships that serve as the basis for measuring responsiveness to habitat manipulation. A set of management activities now must be defined and linked to this framework.[2] It is through this linkage that management activities explicitly influence overall habitat suitability. Thus, expansion of the HSI modeling framework to incorporate the influence of management activities on habitat suitability enables planners and wildlife managers to measure expected biological outcomes.

Economic Choice Criterion

The final step is to incorporate an economic choice criterion that enables decision makers to select economically efficient and rational management activities. In a classic sense, this problem embraces both costs and benefits of these activities. By establishing the costs per unit of management activity, the total cost of the management plan can be readily calculated. On the other hand, benefit valuation poses a difficult problem. Not only is this valuation process conceptually difficult, but it has left biologists in a powerless position when confronting the proponents of economic development. It is here that difficulties in valuing non-market wildlife resources emerge. Non-market valuation techniques may be useful in measuring one dimension of wildlife resources, their recreational value, but no consideration is given to their ecological value. At best, the valuation process is partial.

An alternative choice criterion to maximizing net benefits is minimization of costs per unit of habitat or wildlife produced, i.e., cost effectiveness. This alternative avoids the non-market valuation process altogether. Admittedly, cost effectiveness analyses give the decision maker greater discretionary influence over the final choice. However, the ultimate choice will be determined by several factors: (1) the monetary resources available for program implementation, (2) the anticipated biological output response, and (3) the success of lobbying efforts by interested parties. Thus, the cost effectiveness approach offers the biological profession defensible and useful information to help decision makers choose among least cost management plans associated with different levels of wildlife output (HSI).

The remainder of this paper presents an example of the expanded HEP model in a cost effectiveness framework. Specifically, this framework is applied to the East High Irrigation Project. Because the model is extremely complex, only a synopsis is presented here (for full details see Hanson 1982).

A Planning Model for Mallard Management

A problem confronting planners in Washington's East High Irrigation Project is the determination of optimal management levels for the entire irrigation project.

[2]The relevant management activities should be defined by a team of experts familiar with species' needs and the particular area to be managed. Biologists from the Soil Conservation Service, U.S. Fish and Wildlife Service, and Washington Department of Game identified the set of potentially relevant management activities and their impact on measurable environmental variables.

Numerous options exist for developing this area as mallard breeding habitat, ranging from passive management (the no action alternative), to intensive habitat development. This synopsis describes the procedures required to formulate a mathematical programming model to determine cost effectiveness.[3] Since the model is designed to formulate the optimum level of mallard management activities, the objective is to minimize the costs of habitat maintenance/development subject to the basic biological model, a minimum level of biological productivity (HSI), and other resources that may be limiting.

Figure 2 illustrates the linkage between the HSI model and the management activities for a single measurable environmental variable—vegetative density in the emergent zone.[4] This particular linkage isolates the portion of the model addressed here. Keep in mind, management activities (Level V of the expanded tree diagram) represent the array of choice available to the planner. Each activity can be employed in different amounts, and each incurs different costs. In turn, each activity has a different impact on habitat quality (suitability). The set of equations required to define the linkages illustrated in Figure 2 are discussed below.

Collectively, all management activities combine to define non-linear relation-

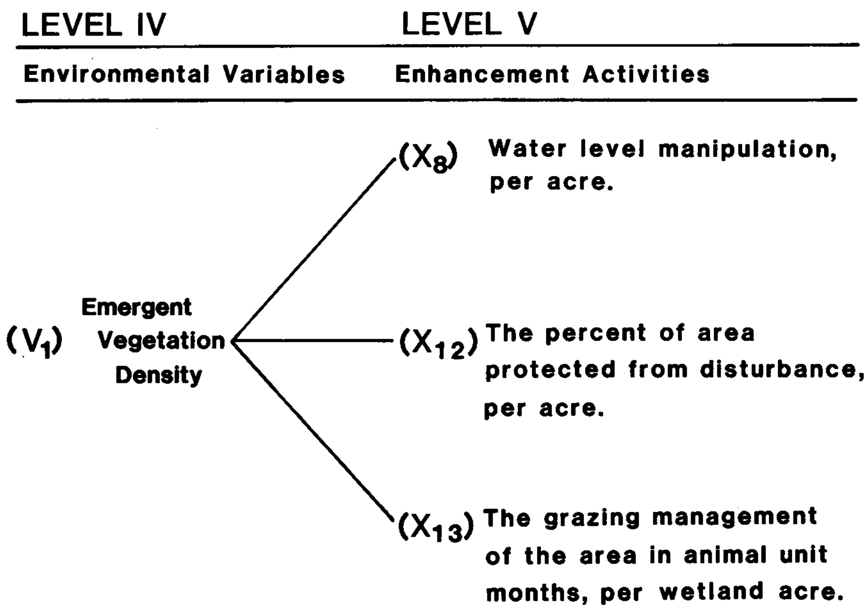

Figure 2. Linkage of management activities to measurable environmental variables.

[3] All constrained optimization problems fall under the generic heading of mathematical programming; the most common of which is linear programming. For further reference see Beale (1968), Hadley (1962, 1964), Hillier and Lieberman (1980), Pfaffenberger and Walker (1976), or Wagner (1975).

[4] Specifically, Figure 2 illustrates the role of emergent vegetation density as related to overwater nesting. This example was chosen despite the fact that overwater nesting is not common behavior for mallards. It is reported in the literature (Krapu et al. 1979) and is included in this general HSI model for completeness.

ships within the HSI model. Consequently, a non-linear programming technique is required to model these relationships. In particular, separable programming is used to estimate cost effective management plans.[5]

Formulation of the separable programming example is divided into two parts. First, a general model description of the linkage between habitat suitability—the constraining biological production criterion—and emergent vegetation density is presented. This description portrays how each management activity influences emergent vegetation density, the overall relationship between the management activities in combination, and habitat suitability of the emergent vegetation density. The second section is a detailed derivation of the specific example equations. Due to the non-linear form of several of the relationships, separable, piecewise linear approximations are formulated.

A General Description of Model Linkages

Modeling the linkage between emergent vegetation suitability and specific management activities is a complex process involving a number of functional relationships nested one into the other. Emergent vegetation suitability, for example, is directly influenced by the percentage of canopy coverage, i.e., density of the emergent vegetation as measured by Daubenmire's technique (1959). This relationship between emergent vegetation suitability and vegetation density is illustrated in Levels III and IV of Figure 1. It is also shown that emergent vegetation suitability is influenced by vegetation height and amount of disturbance, but these two environmental variables will not be discussed here. Rather, the only nested functions described here are those linking emergent vegetation suitability, as defined by vegetation density, to the management activities that impact that density.

Suitability of emergent vegetation depends on vegetation density (Figure 3). Density, in turn, is directly affected by three management activities: (1) water level manipulation per acre of pond (X_8), (2) the percentage of area protected from disturbance (X_{12}), and (3) grazing management of the area measured in animal unit months per wetland acre (X_{13}). Each management activity influences emergent vegetation differently, as shown in figures 4–6, and described in detail below.

On a per acre basis, vegetation management can be undertaken at different time intervals. The longer the interval, the less impact there is on vegetation density given constant management intensity (Figure 4).

Animal grazing and human disturbance affect the density of emergent vegetation by trampling areas where emergents grow. Although emergent species are not a preferred food, livestock will graze on this vegetation if upland food is unavailable or unpalatable. Because cattle do not selectively thin when they feed, any grazing is likely to create open patches in the emergent canopy. Thus, the percentage of wetland which is protected from animal disturbance will impact the overall emergent vegetation density (Figure 5).

[5]Separable programming is a method for optimizing non-linear objective functions and constraints. By transforming non-linear expressions into piecewise linear approximations, modified linear programming algorithms can be used to solve the constrained optimization problem. For further discussion on separable programming see Hadley (1964).

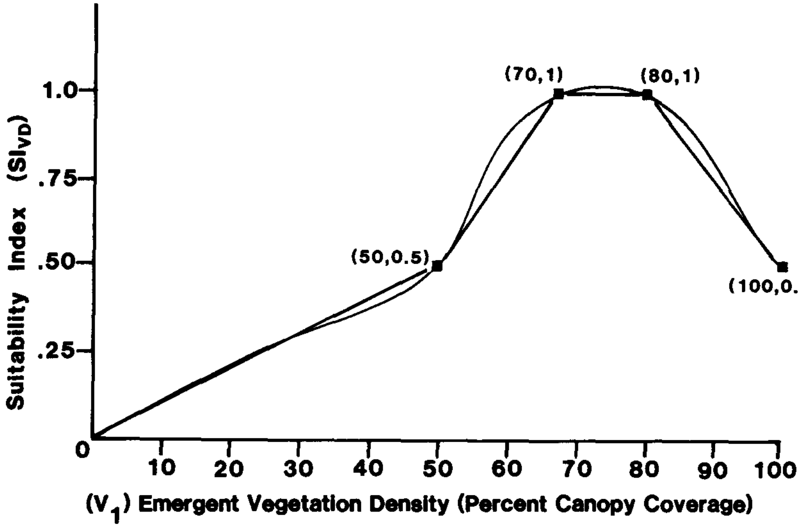

Figure 3. Emergent vegetation density suitability index curve for overwater nesting.

A separate activity monitoring the grazing plan of the wetland is needed, not because of the disturbance factor, but because grazing leases provide an option for generating revenues from these lands. These funds can be used to help offset the mallard management costs. The extent to which grazing can be allowed depends on the tradeoffs between habitat suitability, costs of vegetation maintenance, and revenues generated from grazing leases. The programming model serves to analyze both the cost/revenue relationships, and the impacts of each activity on emergent density and its attendant suitability. The fewer animal unit months per wetland acre of grazing allowed, the greater the vegetation density and thus, the higher the habitat suitability (Figure 6).

Before discussing the specific form of each activity/vegetation density relationship, one final functional linkage must be presented. The role of each management activity, in terms of its vegetational influence, must be linked with the others to determine an overall vegetation influence. This composite value for vegetation density is linked to the overall density suitability index (Figure 3).

The relationship between these three management activities and overall emergent vegetation density is compensatory. A high level of fencing offers protection from grazing disturbance. This protection offsets the need for grazing management, which is presumed to be beneficial only in generating revenues. These two management practices, in turn, tradeoff with the water level manipulation activity. The functional form of this relationship is given in equation (1).

(1) $V_1 = \frac{1}{2} V_{D8} + \frac{1}{2} (V_{D12} * V_{D13})^{1/2}$

Overall emergent vegetation density (V_1) is the average of vegetation densities (V_{Di}) resulting from the three management practices: the water level manipulation

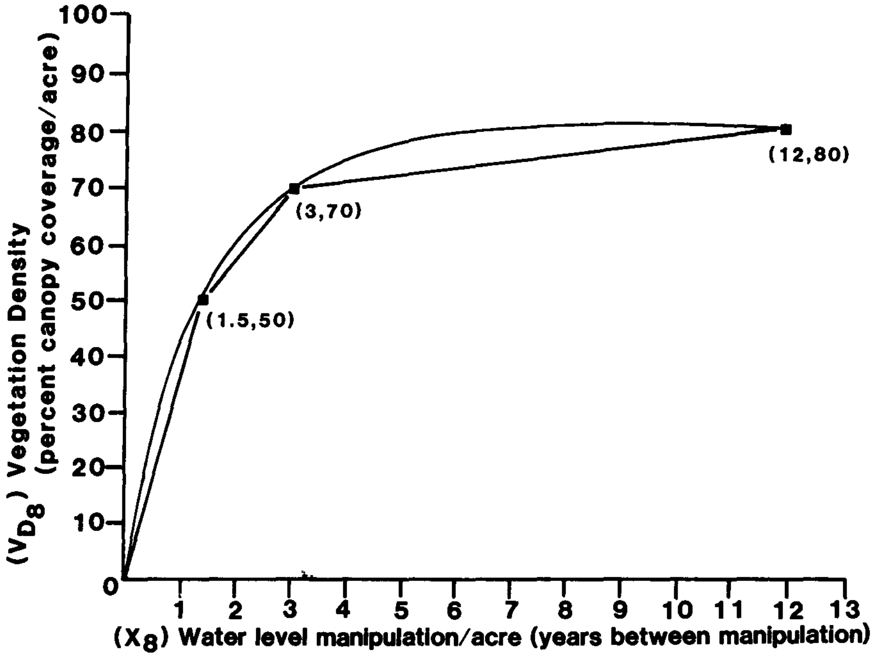

Figure 4. Relationship between water manipulation and emergent vegetation density.

activity (X_8) and the protection and grazing management activities (X_{12} and X_{13}). The percentage of area protected from grazing and grazing management are both required if either is employed. Thus, a geometric mean serves to aggregate the associated vegetation densities, V_{D12} and V_{D13}. If the percentage of the area protected is low, a strict grazing control policy would offset the potential impact of insufficient fencing on the vegetation density, and vice versa. The next step is to specify the functional forms representing these linkages. Readers uninterested in the specific mathematical derivations may skip the next section with little loss in continuity.

Mathematical Formulation of the Specific Example Equations

Functional representation of emergent vegetation suitability clearly involves both linear and non-linear relations as evident from figures 3 through 6. The non-linear functions portrayed in figures 3 and 4 may be approximated directly as separable, piecewise linear equations. However, aggregation of V_{D12} and V_{D13} in equation (1) involves a somewhat more complex non-linearity because the product of V_{D12} and V_{D13} must be transformed into separable linear combinations of the two variables. Each of the necessary equations can provide a fully equivalent, yet separable expression of the relationship between V_{D12} and V_{D13}. Two common methods exist to achieve separability: (1) log transformation, and (2) the difference

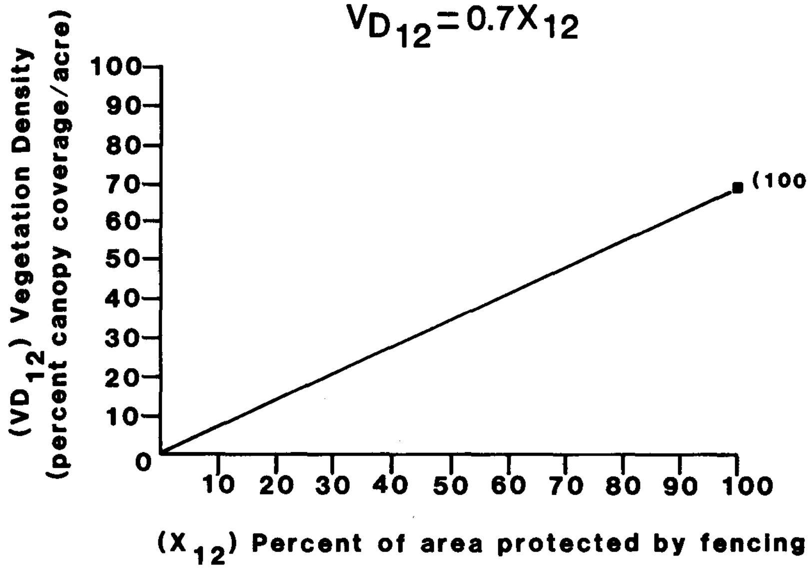

Figure 5. Relationship between percentage of area protected by fencing and emergent vegetation density.

of two squares transformation. For the sake of simplicity, the first of these methods is employed here.

The first step in formulating the mathematical model involves deriving the equations relating management activities to their respective influences on emergent vegetation density. Secondly, these three density expressions must be aggregated into a single, overall density expression. The final linkage relates overall density to emergent vegetation suitability. This process is developed below for each functional relationship in this synopsis of the HSI model.

A set of grid points that define the piecewise linear approximation to the nonlinear function(s) must be selected to closely approximate that function(s). These grid points are the endpoint coordinates of the line segments defining the linear approximation. In this example, the grid points designating the values of V_1, and thus the V_{D_i}'s correspond to 0, 50, 70, 80, and 100.[6] These values closely approximate the suitability index curve in Figure 3.

The relationship between the water manipulation activity (X_8) and emergent vegetation density (V_{D8}) is convex and non-linear (see Figure 4). The vegetation density/management activity curve is piecewise linearly approximated by selecting (0,0), (1.5, 50), (3, 70), and (12, 80) as the grid points. Table 1 demonstrates the

[6]In cases where the upper bound of the relationship is achieved before vegetation density reaches 100 percent, fewer grid points may be selected, as with X_8. Figure 4 illustrates that emergent vegetation density, as influenced by water manipulation, reaches its maximum value at 80 percent. Thus, 100 percent vegetation density cannot be attained and no corresponding value of X_8 can be specified.

Table 1. Linearizing variable coefficient derivation: X_8 and V_{D8}.

Variables			Coordinate values				
X_8	0.0		1.5		3.0		12.0
V_{D8}	0.0		50.0		70.0		80.0
Slope components							
ΔX_8		1.5		1.5		9.0	
ΔV_{D8}		50.0		20.0		10.0	
Linearizing variable				Coefficients			
$\frac{\Delta V_{D8}}{\Delta X_8}$		33.3		13.3		1.1	

derivation of the slope coefficients in the linear approximation of Figure 3. Letting α_i represent the special "linearizing" variable, the relationship between the water manipulation activity (X_8), and emergent vegetation density (V_{D8}) can be approximated by equations (2) through (6):

(2) $V_{D8} = 33.3\alpha_1 + 13.3\alpha_2 + 1.1\alpha_3$

(3) $X_8 = \alpha_1 + \alpha_2 + \alpha_3$

(4) $\alpha_1 \leqslant 1.5$

(5) $\alpha_2 \leqslant 1.5$

(6) $\alpha_3 \leqslant 9.0.$

The percentage of area fenced (X_{12}) is shown in Figure 5 to be linearly related to emergent vegetation density (V_{D12}). Thus, a single linear expression can serve to constrain the optimizing model in terms of this management activity:

(7) $V_{D12} = 0.7\,X_{12}.$

As Figure 6 illustrates, the relationship between grazing management and vegetation density is also linear. The amount of livestock grazing (X_{13}) is inversely proportional to emergent vegetation density (V_{D13}):

(8) $V_{D13} = 70 - 35\,X_{13}.$

Aggregation of these three independent relationships as defined by equations (2) through (8) now may be formulated. Use of the geometric mean to aggregate V_{D12} and V_{D13} in equation (1) requires writing the product term

$$\tfrac{1}{2}(V_{D12} * V_{D13})^{1/2}$$

in terms of separable functions. To do this, first add an equation defining a new varible (Z):

(9) $Z = \tfrac{1}{2}\ln V_{D12} + \tfrac{1}{2}\ln V_{D13}.$

It follows that the geometric mean, $(V_{D12} * V_{D13})^{1/2}$ can be written as:

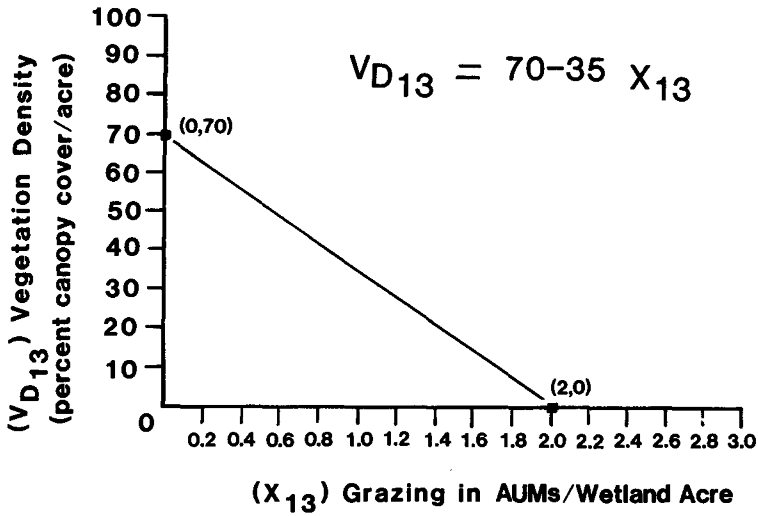

Figure 6. Relationship between grazing plan and emergent vegetation density.

(10) $U = e^Z$.

This equation, along with (9) is added to the model. Finally, equation (1) is restated as:

(11) $V_1 = \frac{1}{2} V_{D8} + \frac{1}{2} U$.

Equation (11) takes the place of equation (1) in the constraint structure. The resulting equations capture the original restrictions on the problem and involve *only* separable, non-linear functions, ln V_{D12}, ln V_{D13} and e^Z.

Further explanation of equations (9) through (11) is warranted to provide clarity. The objective is to define V_1 (overall vegetation density) as a linear combination of the separable functions. Since the log transformation is used to "separate" V_{D12} from V_{D13} in equation (1), several steps are required to link each V_{D_i} with the overall vegetation density. Logarithms of V_{D12} and V_{D13} are used to define a new variable Z. Once Z is defined (V_{D_i}'s have been transformed), an anti-log is required to return the geometric mean back to non-log scale (equation (10)). This defining equation insures that the final answer will be in units compatible with the input data. In summary, equation (9) defines the log of the geometric mean in terms of separable functions of V_{D12} and V_{D13}, and equation (10) relates the log of the geometric mean back to the geometric mean. The end result is a system involving only separable functions which relate the management activities to the overall emergent vegetation density. Equations (9) to (11) now can be cast in the separable programming framework.

Figure 7 illustrates the relationship betweeen vegetation density (V_{D12}) to one half its log. In approximating the curve with grid points, V_{D12} values of one and

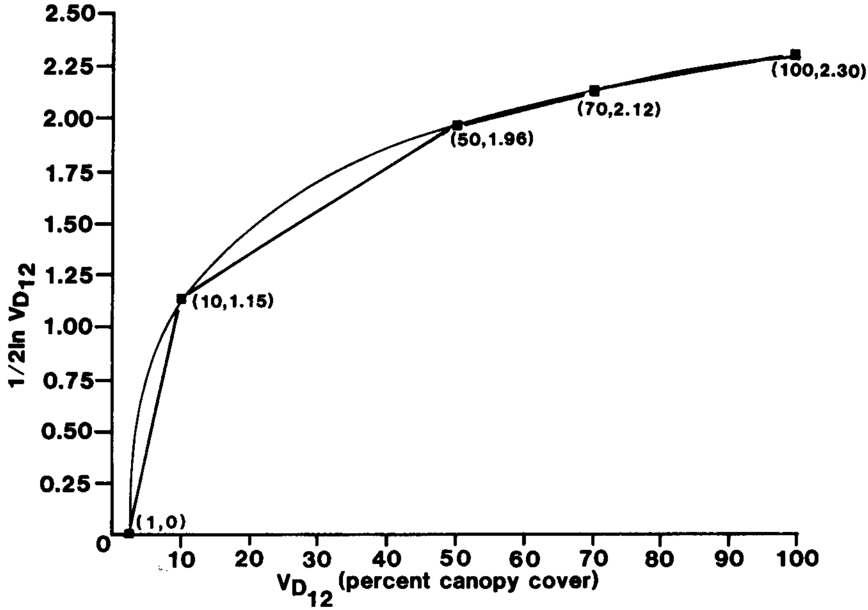

Figure 7. Relationship between V_{D12} and ½ ln V_{D12}.

ten are chosen to accurately estimate the left-hand segment of the curve. Points representing 50, 70, and 100 are selected, as before, to correspond to the grid points of the density/suitability index curve. The linearizing equations are presented below as formulated in Table 2. Using β_i as the special "linearizing" variable for V_{D12}, V_{D12} and ½ ln V_{D12} can be represented as in equations (12) through (17):

(12) $\frac{1}{2} \ln V_{D12} = 0.128\beta_1 + 0.020\beta_2 + 0.008\beta_3 + 0.006\beta_4$

(13) $V_{D12} = \beta_1 + \beta_2 + \beta_3 + \beta_4$

(14) $\beta_1 \leq 9$

(15) $\beta_2 \leq 40$

(16) $\beta_3 \leq 20$

(17) $\beta_4 \leq 30$.

Using δ_i as the linearizing variable, V_{D13} and ½ ln V_{D13} are defined with equations (18) through (23):

(18) $\frac{1}{2} \ln V_{D13} = 0.128\ \delta_1 + 0.020\ \delta_2 + 0.008\ \delta_3 + 0.006\ \delta_4$

(19) $V_{D13} = \delta_1 + \delta_2 + \delta_3 + \delta_4$

(20) $\delta_1 \leq 9$

(21) $\delta_2 \leq 40$

(22) $\delta_3 \leq 20$

(23) $\delta_4 \leq 30$.

The right-hand sides of equations (12) and (18) are then substituted for ½ ln V_{D12} and ½ ln V_{D13} respectively in equation (9), thereby defining Z.

Table 2. Linearizing variable coefficient derivation: V_{D12} and ½ ln V_{D12}.[a]

Variables	Coordinate values								
V_{D12}	1		10.0		50.0		70.0		100.0
½ ln V_{D12}	0		1.15		1.96		2.12		2.30
Slope components									
ΔV_{D12}		9.0		40.0		20.0		30.0	
Δ½ ln V_{D12}		1.15		0.81		0.16		0.18	
Linearizing variable	Coefficients								
$\frac{\Delta ½ \ln V_{D12}}{\Delta V_{D12}}$		0.128		0.020		0.008		0.006	

[a]The same derivation applies to V_{D13} and ½ ln V_{D13}.

Figure 8 illustrates the relationship between the anti-log function "e", and the sum of the log transformed V_{D_i}. A greater number of grid points are required to allow for the various combinations of each V_{D_i} that might result in significant alterations in overall suitability. The coefficients for the linearizing variables, λ_i, are presented in Table 3. Relevant constraint equations are defined by equations (24) through (32):

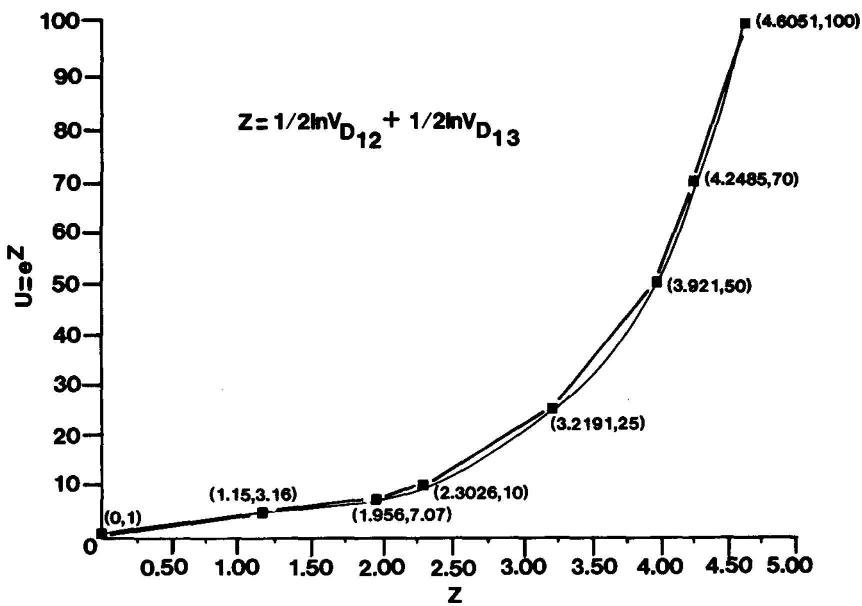

Figure 8. Relationship between Z and U.

Table 3. Linearizing variable coefficient derivation: Z and U.

Variables								Coordinate values							
Z	0.0		1.15		1.96		2.30		3.22		3.92		4.25		4.60
U	1.0		3.16		7.07		10.00		25.00		50.00		70.00		100.00
Slope components															
ΔZ		1.15		0.81		0.34		0.92		0.70		0.33		0.35	
ΔU		2.16		3.91		2.93		15.00		25.00		20.00		30.00	
Linearizing variable								Coefficients							
$\frac{\Delta U}{\Delta Z}$		1.878		4.851		8.444		16.376		35.612		60.975		84.034	

(24) $U = 1.878\lambda_1 + 4.851\lambda_2 + 8.444\lambda_3 + 16.376\lambda_4 + 35.612\lambda_5 + 60.975\lambda_6 + 84.034\lambda_7$

(25) $Z = \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7$

(26) $\lambda_1 \leq 1.15$

(27) $\lambda_2 \leq 0.806$

(28) $\lambda_3 \leq 0.347$

(29) $\lambda_4 \leq 0.916$

(30) $\lambda_5 \leq 0.702$

(31) $\lambda_6 \leq 0.328$

(32) $\lambda_7 \leq 0.357$.

The final step is to link, mathematically, overall emergent vegetation density to emergent vegetation suitability. Coefficients for the linearizing variables are listed in Table 4. SI_{VD} is the overall suitability index value for emergent vegetation density. The constraint set consists of the following system of linear equations, with γ_i as the linearizing variable for V_1:

(33) $SI_{VD} = 0.010\,\gamma_1 + 0.025\,\gamma_2 - 0.025\,\gamma_4$

(34) $V_1 = \gamma_1 + \gamma_2 + \gamma_3 + \gamma_4$

(35) $\gamma_1 \leq 50$

(36) $\gamma_2 \leq 20$

(37) $\gamma_3 \leq 10$

(38) $\gamma_4 \leq 20$.

In summary, a series of nested relationships (some linear, some non-linear) are transformed into a system of linear equations. With these constraints and defining relationships, it is possible to use separable programming to determine the cost effective level of each management activity to achieve a given emergent vegetation density suitability of overwater nesting habitat. It is important to remember that this formulation results in a single environmental variable suitability index. The overall model consists of numerous indexes which must be aggregated and spatially interspersed to generate HSI in much the same fashion as above.

By fixing the level of HSI, optimization of the mathematical programming model yields the least cost set of management activities that achieve the specified HSI value. Parametric variation of HSI traces out a cost effective frontier from which decision-makers can choose a desired plan. See Hanson (1982) for the complete model.

Summary, Conclusions, and Implications

The HSI model framework can serve as a planning tool in resource development. However, the basic framework needs expansion to include the influence of potential management practices, and an economic choice criterion to choose among alternative management plans. This expansion is accomplished in a step-wise manner and requires the use of mathematical programming methods to determine optimal (cost effective) management strategies. The cost effectiveness framework provides a decision-making tool that avoids the tenuous non-market resource valuation process.

Modeling environmental relationships may be a complex procedure. When an

Table 4. Linearizing variable coefficient derivation: V_1 and SI_{VD}.

Variables				Coordinate values					
V_1	0		50.0		70.0		80.0		100.0
SI_{VD}	0		0.5		1.0		1.0		0.5
Slope components									
ΔV_1		50.0		20.0		10.0		20.0	
ΔSI_{VD}		0.5		0.5		0.0		−0.5	
Linearizing variable					Coefficients				
$\frac{\Delta SI_{VD}}{\Delta V_1}$		0.01		0.025		0.0		−0.025	

environmental model is used as a planning device, sufficient detail must be incorporated to accurately depict biological responses from management activities. There appears to be a tendency among most wildlife managers to opt for overly simplistic models comprised of few variables. These models may fail to adequately portray the biological system, and thus, may be incapable of systematically tracing out the integrated responses of a given management option.

The need for selecting *optimal* plans further aggravates the complexity of this analysis. Once the habitat model is formulated and linked to an array of management activities, it must be cast in a mathematical programming framework. The specific example presented in this paper illustrates the relationship between only three management activities and one segment of the biological production model. Thirty-eight equations are needed to characterize this relationship in the separable programming framework. Specification of the complete model requires many more equations.

The high degree of biological and mathematical sophistication required to develop cost effective plans necessitates collaboration of several experts: field biologists, research biologists, mathematical modelers and resource economists. The research biologists, modelers and resource economists must work together to formulate a viable analytical framework. Availability of a library of general wildlife habitat models would expedite this process. These models should be sufficiently detailed to be adaptable to different environmental scenarios. Management experience of the field biologist is needed to frame the problem in a particular application, and to validate the resultant model. Failure to collaborate is likely to perpetuate the role of biologists as impact mitigators rather than as partners in planning.

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